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44.1 INTRODUCTION

Falsework is a temporary structure erected to support loads during construction. In concrete construction, the terms falsework and formwork are used synonymously to include temporary piling and shoring, mud sills, forms for beams or slabs, lateral bracing, hardware and sheathing.

Provision of bridge falsework plans is the responsibility of the contractor. The plans are subject to examination and approval by the engineer. Generally, the structural falsework plans are presented to the District Office. They are forwarded to Structures Design only on complex structures for review. The plans are checked for completeness and structural adequacy. The means of providing for roadway crown, structure camber and deflections must be shown. Also, the plans are checked for compliance with special provisions for clearance requirements. The review and/or approval of falsework plans does not exempt the contractor from the responsibility of obtaining satisfactory results. This review and/or approval indicates that the assumed design loadings in combination with design stresses shown; proposed construction methods, placement rates, equipment, and sequences; the proposed form materials; and the overall scheme of formwork are deemed capable of producing the desired concrete in an acceptable manner.

The objection in falsework planning is to achieve safe performance and a quality final product at the lowest overall cost for the project. Since falsework erection is a substantial part of the total cost of building a structure it is natural to assume that the falsework plan that requires the lowest overall cost will produce the highest project profits. However, other cost related factors such as placement of reinforcing, efficiency of concreting and concrete finishing as well as the use of required hoists, cranes and other equipment may be the deciding factor between two alternate plans. Short-cuts in design or erection of falsework that endanger quality and safety lead to false economy. For example, if forms do not produce the required surface finish, considerable hand rubbing of the concrete is required or if the forms deflect or bulge excessively, expensive chipping or grinding is required. Unnecessary labor costs or falsework failures can rapidly consume construction profits.

44.2 FALSEWORK FAILURES

Falsework failures generally occur at the time of concrete placement. A system of formwork being filled with wet concrete usually has an eccentric loading at its top. Generally a member gives way due to an unexpected effect, other members become misaligned or overloaded and either part or the whole formwork collapses. Most failures result in only partial formwork collapse. An interesting aspect of formwork failures is that often the same forms and design configuration have been used several times without mishap. Many formwork failures can be attributed to human error or omission rather than basic inadequacy of the design. Careful supervision and continuous inspection of formwork erection will prevent many accidents.

Common causes of failure are inadequate cross or diagonal bracing, unbalanced concrete placement causing horizontal thrust, mud sill settlements and localized material weakness leading to overstress. Occasionally failure results from the oversight of not completely tightening column friction collars or expandable types of formwork after installation. Multiple planes of formwork blocking material are susceptible to slipping between layers which can lead to failure. Falsework may collapse when supporting shores or jacks are displaced by vibrations from passing traffic, the movement of men and equipment on the formwork or from vibration of concrete during placement.

The temperature and rate of vertical placement of concrete are major factors influencing the lateral pressure that acts on formwork. If the temperature drops during a pour, concrete setting is retarded, causing additional lateral pressure unless compensated for by reducing the rate of pour.

Other failures are related to formwork details such as inadequate locking devices on metal shoring, inadequate anchorage against uplift for sloping form faces, or lack of bracing or tying corners. Also, insufficient support to prevent rotation of beams or girders where slabs frame into them can result in formwork failure or incorrect deck or slab elevations.

Other deficiencies in the completed structure are caused by premature form stripping, removal of shores, or careless practice in reshoring. The result is usually the sagging of partially cured concrete and development of fine hairline cracks which later require maintenance. Improper spacing of reshoring can lead to formwork collapse during construction. Prior experience and thorough inspection can prevent many falsework failures and result in quality construction.

44.3 FALSEWORK PLANS

Falsework plans must be accurate and complete. Freehand sketches are not accepted for review. The ideal set of plans contains essential details, notes and instructions for constructing falsework. The plans are not cluttered with unnecessary lines, marks, symbols or dimensions. Three sets of falsework plans are required for review.

Required falsework details and informational notes are as follows:

(1) Elevation Views

Show elevations of the overall falsework scheme. The size and location of the following components must be given.

- A. Mud sills*
- B. Columns or Piles
- C. Column Caps (Headers)*
- D. Joists*
- E. Sheathing
- F. Lateral Bracing as Shown
- G. Hardware for Bracing, Brackets, etc.

(2) Cross Sections

Show a cross sectional view of falsework and superstructure. The size and location of the following components must be given unless it has been noted in the elevation view.

- A. Mud sills*
- B. Columns or Piles
- C. Column Caps (Headers)*
- D. Stringers*
- E. Joists*
- F. Sheathing
- G. Lateral Bracing as Shown
- H. Hardware for Braces, Brackets, etc.

(3) Plan Notes

The following data or information, where applicable, is given on the plans.

- A. Piles, if used, must have their approximate bearing capacities recorded. Pile supports are required on stream crossings if piles are used on the main structure.

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- | B. Mud sills, if used, must have the allowable soil bearing capacity recorded. This value on soil shall not exceed 1 ton per square foot unless justified.
- C. If commercial manufactured falsework or shoring is used, give the manufacturer's rated capacity of each type used.
- D. If shoring or struts are placed on the edges of existing footings, the capacity of the footings must be checked. The location of bearing on the footings must be shown on the falsework plans.
- E. Formwork plans must show the necessary elevations to insure the correct lines and grades of finished concrete. If camber is required, the method of forming for this must be given.
- F. If any falsework member has a theoretical deflection of 1/4 inch or more, this deflection is given on the plans noting that this deflection will be adjusted in the field. Positive means of adjustment such as jacks, shims or wedges must be provided to permit realignment or readjustment of the formwork.
- G. Show type and allowable stresses of materials employed if other than given in the section on Falsework Materials.
- * Length of members must be given on plans.

44.4 FALSEWORK MATERIALS

Materials traditionally used for formwork are timber and steel. Timber is predominant because it can easily be cut and shaped using hand tools. Steel has been the choice when high stresses are involved and where repetition of structural sections permit the reuse of modular panel formwork. Plastics, light metals, glass fibers, hardboard and rubber materials have been used to simplify formwork. Suppliers offer panels, walings, strongbacks and form accessories to meet a variety of specific needs.

(1) Allowable Timber Stresses

It is assumed that Construction Grade (1500 f) Douglas Fir, Coastal Region, timber is used unless otherwise noted on the plans.* Timber can be used material but must conform to plan dimensions. Providing for a 25 percent increase in stresses for temporary construction loading, the following maximum design stresses are allowed:

A.	Bending	1875 psi
B.	Horizontal Shear	150 psi
C.	Compression Perpendicular to Grain	500 psi
D.	Compression Parallel to Grain	1500 psi
E.	Basic Modulus of Elasticity	1,760,000 psi

(2) Allowable Steel Stresses

It is assumed that all steel used in the plans conforms to ASTM A36 steel unless otherwise noted. The maximum design stresses including a 25 percent stress increase are as follows:

A.	Bending	25,000 psi
B.	Shear	15,000 psi
C.	Basic Modulus of Elasticity	29,000,000 psi

(3) Design Considerations:

- A. It is assumed that all lumber is S4S (surfaced four sides) and weighs 40 pounds per cubic foot.
- B. The loads superimposed onto the falsework are 10 pounds per square foot live load and 160 pounds per cubic foot for concrete.
- C. When the total length of two or more spans is 16 feet or less, it is assumed that one piece of material is used. Therefore, a continuous design analysis is used for this member. The approximate lengths of all members must be given on the plans.
- D. All loads are assumed uniformly distributed. The loads on sheathing, joists and studs are always distributed although not always uniformly. Loads on

ledgers, stringers, walers, etc. are applied at points where joists or studs bear on them. However, it is convenient and sufficiently accurate to employ an equivalent uniform load for falsework design approximations.

- E. Strength of nailed connections is neglected in determining size of main members. This does not apply when considering hardware strength required for braces, brackets, hangers, splices, etc.
- F. Steel beams must have adequate bracing to prevent lateral buckling of the compression flange. All bracing must be designed to provide an adequate slenderness ratio for the load supported and anchored to insure stability of the total system.
- G. Reference is made to the Wisconsin Standard Specifications for Road and Bridge Construction for minimum highway clearance and concrete cure requirements.

* Allowable design stresses are based on AASHTO Specifications for Highway Bridges.

44.5 LATERAL FORM PRESSURE

Freshly placed concrete in wall or column forms behaves temporarily like a fluid prior to its setting producing lateral pressures on the forms. This pressure is comparable to full liquid head if the concrete is placed full height within the time period required for initial set. The effective lateral pressure on the forms is influenced by the rate of placement, temperature and weight of the concrete mix, depth of the pour, use of admixtures and effects of vibration.

The rate of placement is the average rate of concrete rise in feet per hour in the forms. Concrete at the bottom of the forms begins to set at slower rates of placement resulting in a reduction in lateral pressure. Temperature affects the setting time of the concrete. At lower temperatures (40-50°F) the concrete takes longer to set and a greater depth of placement occurs before the lower portion becomes firm and self-supporting.

ACI Committee 347 studied available data and recommended lateral pressure equations for wall and column forms based on the rate of placement under normal internal vibration, maximum slump and height and temperature of the fresh concrete in the forms. The equations for wall and column forms are as follows:

(1) Wall Forms

Recognizing the possibility of controlled, relatively slow rates of placement where lateral pressure is limited as concrete begins to set as well as the possibility of rapid rates of placement greater than 10 feet per hour; ACI Committee 347 recommends three equations for computing maximum lateral pressure.

For walls not exceeding a 7 foot per hour rate of placement:

$$p = 150 + \frac{9000R}{T} \quad \text{where the maximum pressure equals 2000 psf or } 150h, \text{ whichever is less.}$$

For walls having a rate of placement from 7 to 10 feet per hour:

$$p = 150 + \frac{43,400}{T} + \frac{2800R}{T} \quad \text{where the maximum pressure equals 2000 psf or } 150h, \text{ whichever is less.}$$

For walls exceeding a 10 foot per hour rate of placement:

$$p = 150h$$

Where: p = maximum lateral pressure, psf.

-
- R = rate of placement, ft. per hr.
T = temperature of concrete in the forms, °F.
h = maximum height of fresh concrete in the forms, ft.

The above equations are derived for concrete made with Type I cement weighing 150 pounds per cubic foot, containing no possolans or admixtures, having a slump of 4 inches or less. If retarding admixtures are employed, an effective value of temperature less than that of the concrete in the forms must be used in the above equations. Refer to specific admixtures manufacturer's recommendations.

(2) Column Forms

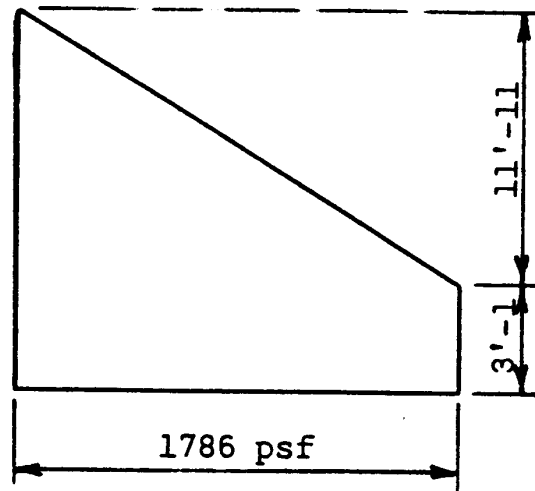
Maximum lateral pressures are realized on column forms since their full height is placed in a relatively short period of time. Vibration frequently extends throughout the full height of the form and concrete set begins after placement is complete. For columns the following equation for lateral pressure is given:

$$p = 150 + \frac{9000R}{T} \text{ where the maximum pressure equals 3000 psf or } 150h, \text{ whichever is less.}$$

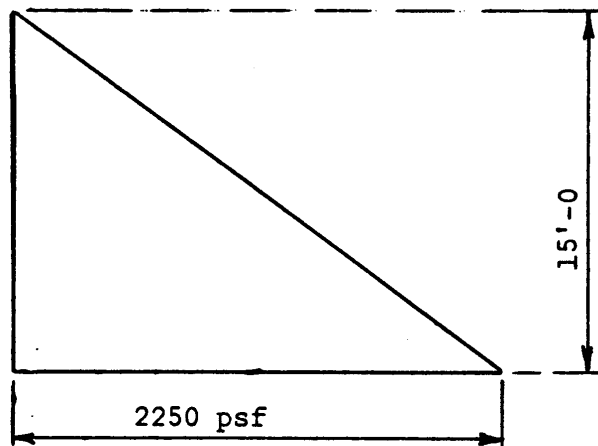
It is recommended for column form design where lifts do not exceed 18 feet and where the maximum horizontal dimension does not exceed 6 feet; otherwise, the wall equations will apply. Temperature must be adjusted if a retarder is used.

Since the lateral pressure on column forms is comparable to fluid pressure up to the time concrete stiffens appreciably, maximum pressure is assumed to increase uniformly at 150 psf per foot of depth until the maximum value of 3000 psf or 150h is reached. The maximum value remains constant throughout the remaining depth of the form.

For example, given a 15 foot high column concreted at R = 10 ft/hr and an effective temperature of 55°F, the equation gives a maximum pressure of 1786 psf. Maximum pressure will occur at a depth of 1786/150 or 11.9 feet below the top of the form and the maximum pressure of 1786 psf applies for design throughout the remaining depth of form. The pressure diagram is as follows:



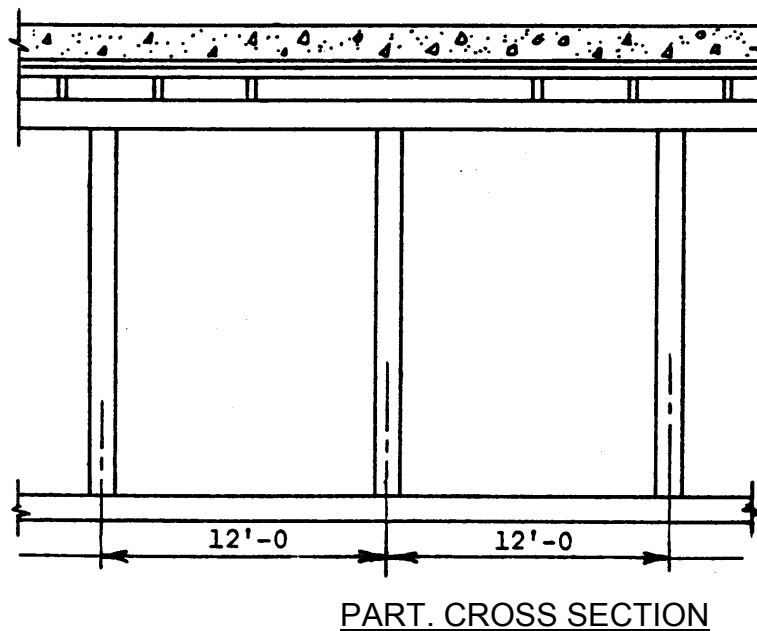
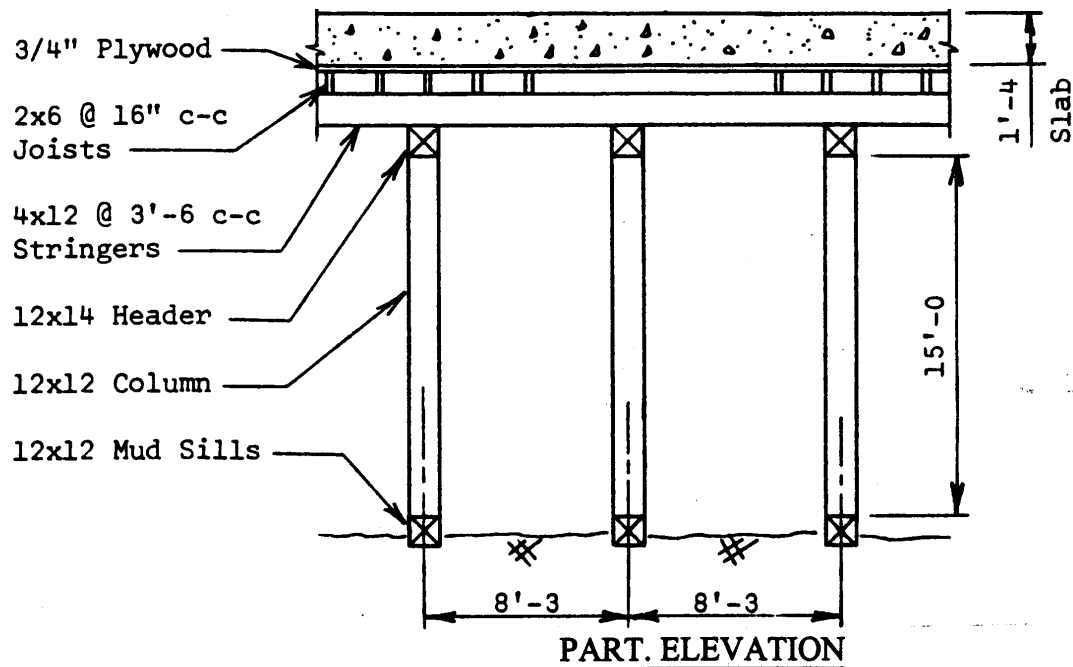
For the same column, concreted at $R = 14$ ft/hr and at an effective temperature of 55°F , maximum pressure is 2441 psf which is greater than $150h$, which equals 2250 psf, the latter value represents the maximum design pressure for the forms. The pressure diagram is as follows:



44.6 DESIGN EXAMPLES

(1) Timber Stringers and Mud Sills

The following layout is given on a set of falsework plans. The design adequacy is checked on the following pages:



Lateral bracing is not shown in either view.

Allowable Stresses

Douglas Fir -----	1500 f
Bending -----	1875 psi
Horizontal Shear -----	150 psi
Compression Perpendicular to Grain -----	500 psi
Compression Parallel to Grain -----	1500 psi
Allowable Soil Pressure -----	1 ton/sq. ft.

Loads

Concrete Dead Load = $1.33(160) =$	213 psf
Form Dead Load	12 psf
Live Load	<u>10 psf</u>
Design Load	235 psf

Check Plywood (3/4")

Assume allowable stresses noted above

Span Length (L) = 1.33 ft. Design Load (w) = 235 #/ft.

Bending

Plywood is continuous over three or more equal spans, maximum moment is computed at the first interior support.

$$M = w(L)^2 / 10 = 235(1.33)^2 / 10 = 41.6 \text{ ft.-\#}$$

$$f = M / S \text{ where } S = b(d)^2 / 6 \text{ for a rectangular section}$$

$$S = 12(3/4)^2 / 6 = 1.125 \text{ in}^3$$

$$f = (41.6)(12) / 1.125 = 444 \text{ psi OK}$$

Horizontal Shear

In accordance with AASHTO Specifications, check shear at the 1/4 span point or at a distance from the support equal to three times the depth of the beam, whichever is the least distance from the support.

$$\text{Span} / 4 = 16 / 4 = 4"$$

$$3d = 3x(3/4) = 2 \text{ 1/4"} \text{ (controls) or check at a distance of}$$

$2.25 / 16 = 0.14L$ from the first interior support. From influence line tables refer to AISC reference for constant I and three equal spans,

$$\text{Shear } V @ 0.14L = (0.60 - 0.14)wL = (0.46)(235)(1.33) = 144\#.$$

$$\text{Shear Stress} = 3V / 2bd = (3)(144) / (2)(12)(0.75) = 24 \text{ psi OK}$$

Deflection

$$\Delta = 0.0069wL^4/EI$$

$$I = b(d)^3/12 = (12)(0.75)^3/12 = 0.422in^4$$

$$\Delta = (0.0069)(235)(1.33)^4(1728) / (1,760,000)(0.422) = 0.012in.$$

Check Joists 2 x 6

Section Properties

$$A = 8.25in^2 \quad S = 7.56in^3$$

$$\text{Span Length (L)} = 3'-6 \quad \text{Design Load (w)} = (2.35)(1.33) = 314 \text{ \#/ft}$$

Bending

$$M = w(L)^2/10 = (314)(3.5)^2/10 = 385 \text{ ft-}\#$$

$$f = M / S = (385)(12) / 7.56 = 611 \text{ psi. OK}$$

Horizontal Shear

Assuming continuity over three or more supports; checking the critical section:

$$\text{Span} / 4 = (3.5)(12) / 4 = 10.5in. \text{ (controls)}$$

$$3d = (3)(5.5) = 16.5in.$$

$$\text{Shear } V @ 0.25L = (0.60 - 0.25)(314)(3.5) = 385\#$$

$$v = 3V / 2A = (3)(385) / (2)(8.25) = 70 \text{ psi. OK}$$

Compression Perpendicular to Grain

Maximum reaction (R) at the first interior support.

$$R = 1.14wL = (1.14)(314)(3.5) = 1253\#$$

$$c_{\perp} = R / A = (1253) / (1.5)(3.5) = 239 \text{ psi. OK}$$

Check Stringers (4 x 12)

Section Properties

$$A = 39.38in^2 \quad S = 73.8in^3 \quad I = 415.3in^4$$

$$\text{Span Length (L)} = 8'-3 \quad \text{Design Load (w)} = (235)(3.5) = 823\#/\text{ft.}$$

Bending

Assume stringers are continuous over two spans, maximum moment at center support.

$$M = w(L)^2/8 = (823)(8.25)^2/8 = 7002 \text{ ft-}\#$$

$$f = M / S = (7002)(12) / 73.8 = 1138 \text{ psi} \quad \text{OK}$$

Horizontal Shear

$$\text{Span} / 4 = 8.25 / 4 = 2.06 \text{ ft.} \quad (\text{controls})$$

$$3d = (3)(11.5) / 12 = 2.88 \text{ ft.}$$

$$V@0.25L = (0.625 - 0.25)(823)(8.25) = 2546 \#$$

$$v = (3)(2546) / (2)(39.38) = 97 \text{ psi} \quad \text{OK}$$

Compression Perpendicular to Grain

$$R = 1.25wL = 1.25(823)(8.25) = 8487 \#$$

$$c\perp = 8487 / (3.5)(11.5) = 211 \text{ psi} \quad \text{OK}$$

Deflection

For two span continuous

$$\Delta = w(L)^4/185EI$$

$$\Delta = (823)(8.25)^4(1728) / (185)(1,760,000)(415.35) = 0.049 \text{ in.}$$

Check Column Cap (12 x 14)

Section Properties

$$A = 155.2 \text{ in}^2 \quad S = 349.3 \text{ in}^3$$

$$\text{Span Length (L)} = 12'-0 \quad \text{Design Load (w)} = (235)(8.25) = 1940 \text{ \#/ft.}$$

Bending

Assume caps are continuous over two spans, maximum moment at the center support:

$$M = w(L)^2/8 = 1940(12)^2/8 = 34,920 \text{ ft-}\#$$

$$f = M / S = 34,920(12) / (349.3) = 1200 \text{ psi} \quad \text{OK}$$

Horizontal Shear

$$Span / 4 = 12 / 4 = 3.0' \text{ (controls)}$$

$$3d = (3)(13.5) / 12 = 3.375'$$

$$V@0.25L = (0.625 - 0.25)(1940)(12) = 8730\#$$

$$v = 3V / 2A = (3)(8730) / (2)(155.2) = 84 \text{ psi} \quad \text{OK}$$

Compression Perpendicular to Grain

$$R = 1.25wL = 1.25(1940)(12) = 29,100\#$$

$$c\perp = 29,100 / (11.5)(11.5) = 220 \text{ psi} \quad \text{OK}$$

Check Column (12 x 12)

Section Properties

$$A = 132.2 \text{ in}^2 \quad P = 29,100\#$$

Compression Parallel to Grain

Assume unsupported length (L) equals 15 ft. Allowable $P/A = 0.30EF/(L/d)^2$
where $E = 1,760,000 \text{ psi}$

$F = \text{overload factor} = 1.25$

$d = \text{dimension of least side in inches}$

$L = \text{unsupported column length in inches}$

$P/A = \text{allowable stress less than or equal to } 1500 \text{ psi.}$

$$\text{Allowable } P/A = (0.3)(1,760,000)(1.25)/(15 \times 12/11.5)^2$$

$$= 2694 \text{ psi greater than } 1500 \text{ psi.}$$

$\therefore \text{Use: } 1500 \text{ psi as maximum allowable } P/A.$

$$\text{Actual } P/A = 29,100/132.2 = 220 \text{ psi.} \quad \text{OK}$$

Check Mud Sills (12 x 12)

Section Properties

$$A = 132.2 \text{ in}^2 \quad S = 253.5 \text{ in}^3 \quad \text{Span Length (L)} = 12'-0$$

Design Load (w) = 1940#/ft. Assume equal distribution over full length of sill.

Bending

$$M = w(L)^2/8 = 34,920 \text{ ft-}\#$$

$$f = M/S = (34,920)(12)/253.5 = 1653 \text{ psi}$$

Horizontal Shear

$$\begin{aligned}\text{Span}/4 &= 12'/4 = 3.0' \\ 3d &= 3(11.5)/12 = 2.88' \text{ (controls)} \\ V &\text{approximately same as cap} = 8730\# \\ v &= (3)(8730)/(2)(132.2) = 99 \text{ psi. OK}\end{aligned}$$

Bending on Soil

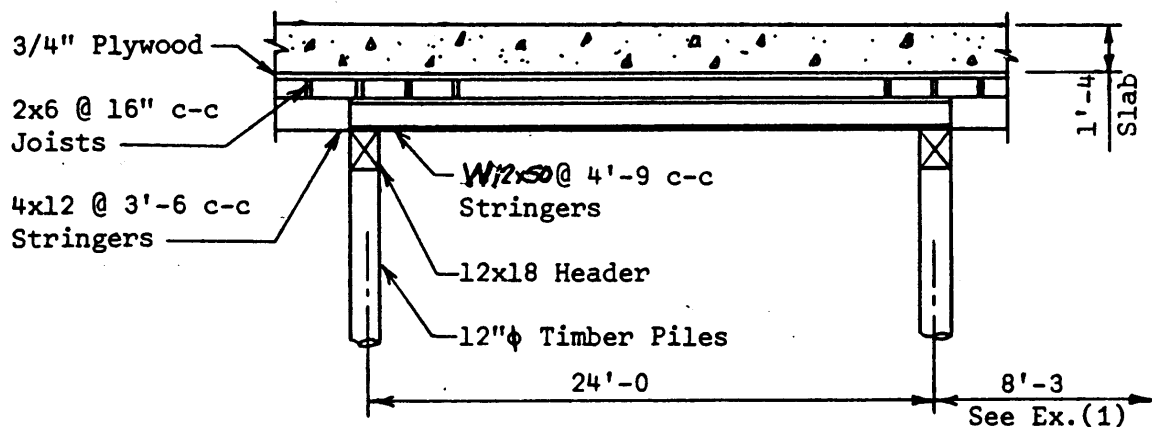
$$\begin{aligned}\text{Allowable } P/A &= 2000 \text{ psf} \\ P &= \text{column design load} = 1.25 wL \\ \text{Actual } P/A &= (1.25)(1940)(144)/(12)(11.5) = 2530 \text{ psf greater than } 2000 \text{ psf. N.G.} \\ \therefore \text{ Use: } &12 \times 16 \text{ mud sills for increased bearing area.}\end{aligned}$$

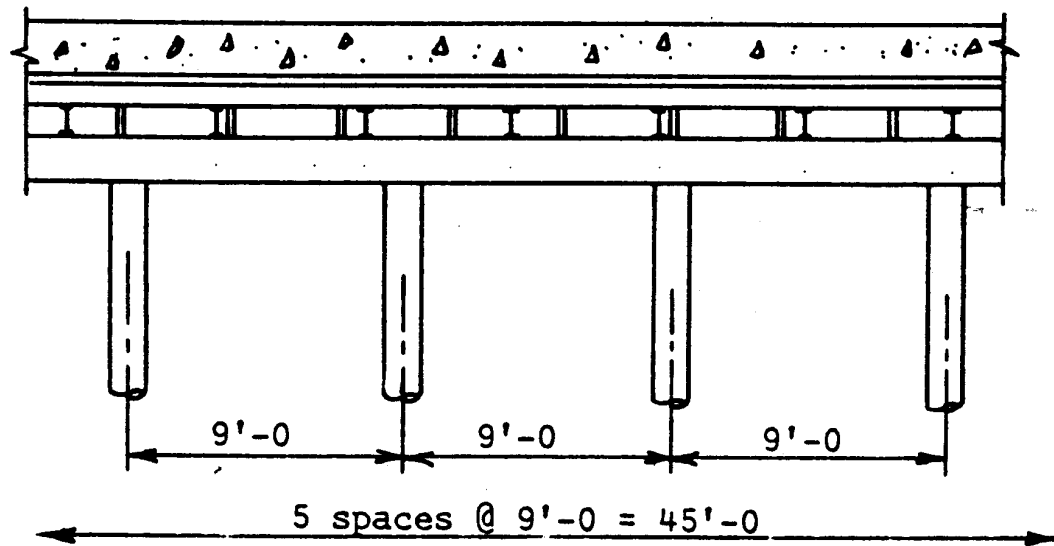
Falsework Bracing

Adequate longitudinal and transverse bracing is required for all formwork. The designer is referred to Article 44.4(3)F. Generally, this bracing is not checked by C.O. personnel.

(2) Steel Stringers and Piling

The following information is given on the falsework plans. The joists, stringers, pile cap and pile capacity are design checked as follows:

PART. ELEVATION



PART. CROSS SECTION

Lateral bracing is not shown in either view.

Allowable Stresses

Douglas Fir 1500 f

Refer to Design Example (1)

Design Load = 235 psf

ASTM A36 Steel

Bending = 25,000 psi

Shear = 15,000 psi

Check Plywood (3/4")

Refer to Design Example (1)

Check Joists (2 x 6)

Section Properties

$$A = 8.25 \text{ in}^2 \quad S = 7.56 \text{ in}^3$$

$$\text{Span Length (L)} = 4'-9$$

$$\text{Design (w)} = 1.33 (235\#/ft) = 314\#/ft$$

Bending

$$M = w(L)^2/10 = (314)(4.75)^2/10 = 708 \text{ ft-}\#$$

$$f = M/S = (708)(12)/7.56 = 1124 \text{ psi} \quad \text{OK}$$

Horizontal Shear

$$\text{Span}/4 = (4.75)(12)/4 = 14.25'' \text{ (controls)}$$

$$3d = 3 \times 5.5 = 15.5''$$

$$V @ 0.25L = (0.60 - 0.25) \times 314 \times 4.75 = 522\#$$

$$v = 3V/2A = (3)(522)/(2)(8.25) = 95 \text{ psi} \quad \text{OK}$$

Compression Perpendicular to Grain

Reaction at first interior support, 3 span maximum

$$R = 1.10 wL = 1.10 \times 314 \times 4.75 = 1641\#$$

$$c_{\perp} = R/A = 1641/(8.08)(1.5) = 135 \text{ psi} \quad \text{OK}$$

Check Stringers (W 12 x 50)

Section Properties

$$A_w = 4.52 \text{ in}^2 \quad S = 64.7 \text{ in}^3 \quad I = 394 \text{ in}^4$$

Span Length (L) = 24'-0

Design Load (w) = (4.75)(235) = 1116#/ft

Bending

$$M = w(L)^2/8 = (1116)(24)^2/8 = 80,352 \text{ ft-#}$$

$$f = M/S = 80,352 \times 12/64.7 = 14,903 \text{ psi OK}$$

Shear

$$V = wL/2 = (1116)(24)/2 = 13,392\#$$

$$v = V/A_w = 13,392/4.52 = 2963 \text{ psi OK}$$

Deflection

$$\Delta = 5w(L)^4/384EI$$

$$\Delta = (5)(1116)(24)^4(1728) / (384)(29,000,000)(394)$$

$$\Delta = 0.73"$$

Say: 3/4" which is greater than acceptable. A stringer having more depth is required or variable shimming of the joists.

Check Pile Cap (12 x 18)

Section Properties

$$A = 201 \text{ in}^2 \quad S = 587 \text{ in}^3$$

Span Length (L) = 9'-0

Design Load = (P₁) = (3)(823)(8.25)/8 = 2546# (4 x 12)

Design Load = (P₂) = (1116)(24)/2 = 13,392# (12W50)

Bending

Assume cap is continuous over two spans, that three 4 x 12's are symmetrically placed in the center of the 9'-0 span, and that the 12W50 is placed at the center of the 9'-0 span for maximum moment.

$$M_1 = 4P_1(0.75L_1 - a) / 5 = 4(2546)((0.75)(9) - 3.5) / 5 = 6620 \text{ ft-#}$$

$$M_2 = P_2 L_2 / 5 = (13,392)(9) / 5 = 24,106 \text{ ft-#}$$

$$M = M_1 + M_2 = 30,726 \text{ ft-#}$$

$$f = M / S = (30,726)(12) / 587 = 628 \text{ psi OK}$$

Horizontal Shear

Assume the first 12W50 is placed at 1'-3 from the center of support and that the first 4 x 12 is located at 2'-0 from the center of support for maximum shear since in this case:

$$3d = 3(1.5') = 4'-6 \text{ or}$$

Span/4 = 9'/4 = 2'-3 from the center of support would give a smaller value of shear.

$$V_1 = 2,546(9 - 2) / 9 + 2,546(9 - 5.5) / 9 = 2,978\#$$

$$V_2 = 13,392 + 13,392(9 - 6) / 9 = 17,811\#$$

$$V = V_1 + V_2 = 20,789\#$$

$$v = 3V / 2A = (3)(20,789) / (2)(201) = 155\text{psi} \quad \text{OK}$$

Compression Perpendicular to Grain

For 12" ϕ timber piling the reaction is:

$$R = 13,392 + (13,392)(0.94) + (2546)(1.69 + 1.05) = 32,956\#$$

$$A = \pi(11.5)^2 / 4 = 103.8\text{in}^2$$

$$c_{\perp} = R / A = 32,956 / 103.8 = 317\text{psi} \quad \text{OK}$$

Pile Capacity (12" ϕ)

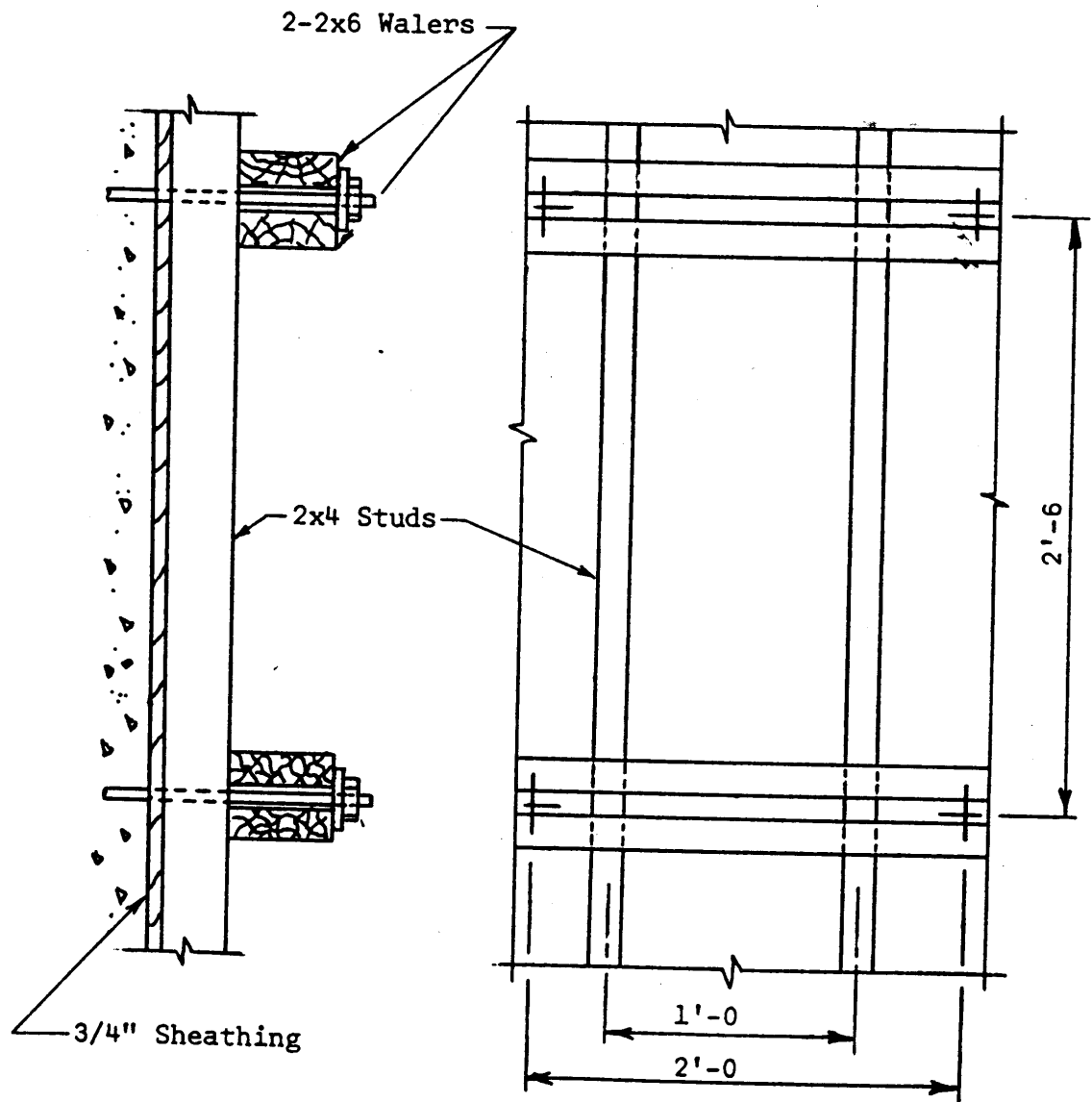
Assume a 1.5 safety factor.

$$P = 1.5R = (1.5)(32,956) = 49,434\#$$

Drive piles to 25 ton minimum capacity.

(3) Timber Studs and Waling

Given the following wall form details, the design is checked as follows:



PART. CROSS SECTION

PART. ELEVATION

Allowable Stresses

Douglas Fir 1500 f

Refer to Example (1) and Section 44.5.

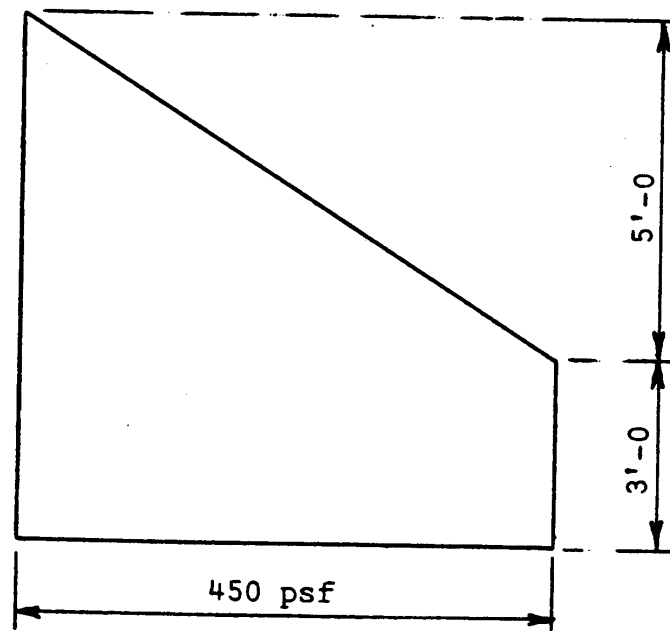
Lateral Form Pressure

Rate, $R = 2$ ft/hr and the effective temperature is 60°F .

$$p = 150 + \frac{9000 \times 2}{60} = 450 \text{ psf (controls)}$$

$$150h = 150(8) = 1200 \text{ psf}$$

$$\text{Depth of maximum pressure} = 450/150 = 3.0'$$

Pressure DiagramCheck Studs (2 x 4)

Section Properties

$$A = 5.25 \text{ in}^2 \quad S = 3.06 \text{ in}^3$$

Span Length (L) = 2'-6" continuous over three spans.

Maximum Design Load = $450 \text{ psf} \times 1 \text{ ft} = 450 \text{ \#/ft}$.

Bending

$$M = w(L)^2 / 10 = 450(2.5)^2 / 10 = 281 \text{ ft-}\#$$

$$f = M / S = (281)(12) / 3.06 = 1102 \text{ psi} \quad \text{OK}$$

Horizontal Shear

$$V = 0.6wL = (0.6)(450)(1.0) = 270 \# \quad \text{OK}$$

$$v = 3V / 2A = (3)(270) / (2)(5.25) = 77 \text{ psi} \quad \text{OK}$$

Compression Perpendicular to Grain

$$R = 1.10wL = 1.10(450)(2.5) = 1238 \#$$

$$c_{\perp} = R / A = 1238 / (1.5)(1.5)(2) = 275 \text{ psi} \quad \text{OK}$$

| Check Walers (2 - 2 x 6)

Section Properties

$$A = 2 \times 8.25 = 16.50 \text{ in}^2$$

$$S = 2 \times 7.56 = 15.12 \text{ in}^3$$

Span Length (L) = 2'-0

Design Load (P) from studs = (450)(1.0)(2.5) = 1125#

Bending

$$M = PL / 5 = (1125)(2) / 5 = 450 \text{ ft-}\#$$

$$f = M / S = (450)(12) / 15.12 = 357 \text{ psi} \quad \text{OK}$$

Horizontal Shear

Place one stud adjacent to tie.

$$V = P + P(L - a) / L = 1125 + 1125(2 - 1) / 2 = 1688 \#$$

$$v = 3V / 2A = (3)(1688) / (2)(16.5) = 153 \text{ psi} \quad \text{OK}$$

Compression Perpendicular to Grain at Tie

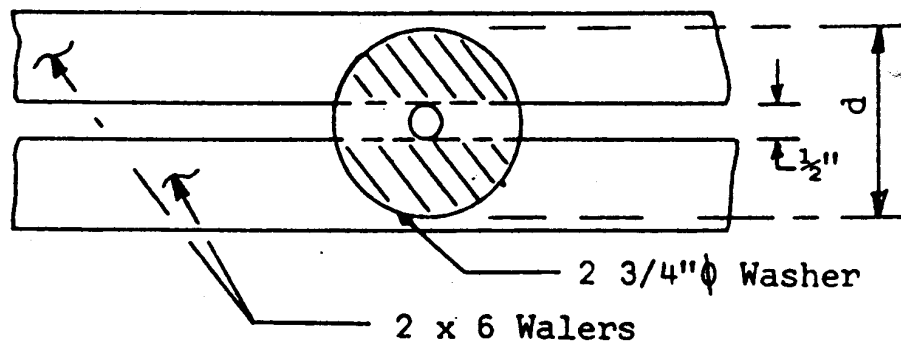
| Assume ties are on continuous walers for a minimum of four spans and that the reaction is computed at the first interior support. Compression perpendicular to the grain can be increased if bearing occurs at a distance of 3 inches or more from the end of the beam and the bearing length is less than 6

inches long. The following equation times the allowable stress in compression perpendicular to the grain gives the increased allowable stress.

Increased Allowable Stress = $((L + 0.375)/L)500$ where L is the length of bearing in inches along the grain of the wood. For round bearing areas, use a length equal to the diameter.

Increased Allowable Stress = $((2.75 + 0.375)/2.75)500 = 568$ psi for a 2-3/4" ϕ washer.

Reaction (R) = $(0.728 + 1.0 + 0.567)P = 2.3P = (2.3)(1125) = 2588\#$



Bearing Area = $\pi(d)^2/4 - (dx1/2) = \pi(2.75)^2/4 - (2.75 \times 1/2) = 5.94 - 1.38 = 4.56 \text{ in}^2$

$c_{\perp} = R / A = 2588 / 4.56 = 568 \text{ psi}$ which equals the increased allowable bearing stress.

Tension in Ties (7/16" ϕ)

Allowable Stress = $1.25 (20,000 \text{ psi}) = 25,000 \text{ psi}$

$A = (\pi)(7/16)^2/4 = 0.15 \text{ in}^2$

R = 2588#

Tensile Stress = $R/A = 2588/0.15 = 17,253 \text{ psi}$ OK

REFERENCES

1. State of Wisconsin, Department of Transportation, Standard Specifications for Road and Bridge Construction.
2. Standard Specifications for Highway Bridges by American Association of State Highway and Transportation Officials.
3. Timber Construction Manual by the American Institute of Timber Construction, John Wiley and Sons, Inc.
4. Formwork for Concrete by M. K. Hird Special Publication No. 4 by American Concrete Institute, 1969.
5. Recommended Practice for Concrete Formwork by American Concrete Institute Committee 347, 1977.